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(54) **METHOD AND APPARATUS FOR VARIABLE REFRIGERANT CHILLER OPERATION**

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F25B 1/00 (2006.01)
F25D 17/02 (2006.01)

(52) **U.S. Cl.**

CPC ***F25B 45/00*** (2013.01); *F25B 2500/19* (2013.01); *F25B 2700/04* (2013.01)

(58) **Field of Classification Search**

CPC F25B 45/00; F25B 2345/001; F25B 2345/002; F25B 2345/006; F25B 2400/16; F25B 41/00; F25B 49/025; F25B 2600/021; F25B 27/00; B60H 1/00585; B60H 1/3208; Y02B 30/741

USPC 62/149, 77, 174, 230

See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

3,264,841 A * 8/1966 Osborne F25B 1/00 62/196.1
4,503,684 A * 3/1985 Mount F04D 27/0246 415/14

(Continued)

FOREIGN PATENT DOCUMENTS

EP 0027604 A2 4/1981
EP 2051037 A2 4/2009

(Continued)

OTHER PUBLICATIONS

LG-ASHRAE Refrigerant Charge Calculation Formula, 2007, p. 2.*

(Continued)

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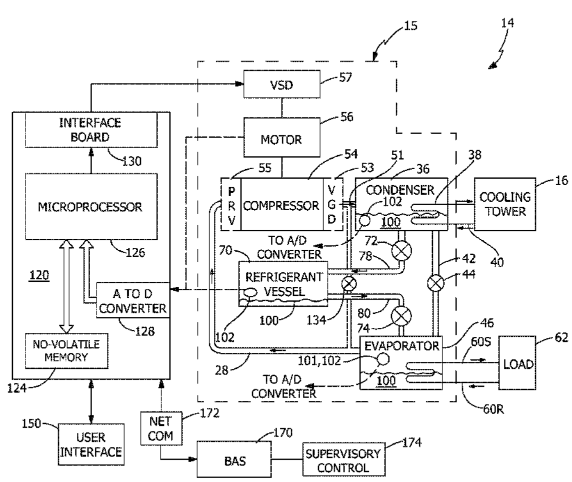
(57) **ABSTRACT**

A refrigeration system includes a compressor, a condenser, an expansion device, an evaporator, and an additional refrigerant vessel connected in a closed refrigerant loop. The additional refrigerant vessel is connected to the condenser at the high pressure side by a first valve and to the evaporator at a low pressure side by a second valve. A controller controls operation of the first valve and the second valve. Only one of the first valve and the second valve may be open at the same time. Refrigerant from the additional refrigerant vessel may be added to the closed refrigerant loop when the controller receives a low refrigerant level indication of in the evaporator. Refrigerant may also be removed from the closed refrigerant loop when the controller receives a high refrigerant level indication in the evaporator.

19 Claims, 8 Drawing Sheets



(56) **References Cited**

U.S. PATENT DOCUMENTS

5,207,074	A	5/1993	Cox et al.	
5,706,665	A *	1/1998	Gregory	F25B 40/00 62/174
6,202,431	B1 *	3/2001	Beaverson	F04D 27/0207 62/196.3
6,209,338	B1 *	4/2001	Thatcher, Jr.	F25B 45/00 62/149
6,357,240	B1 *	3/2002	Zugibe	F25B 45/00 62/149
6,427,464	B1 *	8/2002	Beaverson	F04D 27/0207 62/129
6,691,525	B2 *	2/2004	Beaverson	F04D 27/0207 62/129
6,772,599	B2 *	8/2004	Bodell, II	F04D 27/0253 62/129
7,356,999	B2 *	4/2008	Bodell, II	F04D 27/0207 415/119
7,376,504	B2 *	5/2008	Zagranski	F02C 9/28 701/100
7,905,102	B2 *	3/2011	Bodell, II	F04D 27/0207 415/119
2002/0092318	A1	7/2002	Tipton et al.	
2002/0170304	A1 *	11/2002	Beaverson	F04D 27/0207 62/228.3
2004/0025523	A1 *	2/2004	Bodell, II	F04D 27/0253 62/228.1
2004/0089015	A1	5/2004	Knight et al.	
2004/0109757	A1 *	6/2004	Nenstiel	F04D 29/464 415/151
2005/0076656	A1 *	4/2005	Bodell, II	F04D 27/0207 62/83
2005/0160748	A1 *	7/2005	Shaffer	F01D 15/08 62/228.1
2006/0147301	A1 *	7/2006	Ueda	F04D 27/0207 415/144
2007/0277537	A1 *	12/2007	Parthasarathy	B64D 13/06 62/129
2008/0216491	A1 *	9/2008	Quest	F25B 49/005 62/77
2009/0025914	A1	1/2009	Knight et al.	
2010/0162739	A1	7/2010	Kopko et al.	
2011/0041523	A1 *	2/2011	Taras	F25B 9/008 62/77
2011/0126559	A1	6/2011	Kopko et al.	
2012/0100011	A1 *	4/2012	Sommer	F04D 27/02 417/44.1

FOREIGN PATENT DOCUMENTS

WO	9964794	A1	12/1999	
WO	2008150289	A1	12/2008	
WO	WO 2009058975	A1 *	5/2009	F04D 17/12
WO	2010008960	A2	1/2010	

OTHER PUBLICATIONS

LG-Understanding and Applying ASHRAE Standards, 2007, p. 2.*

* cited by examiner

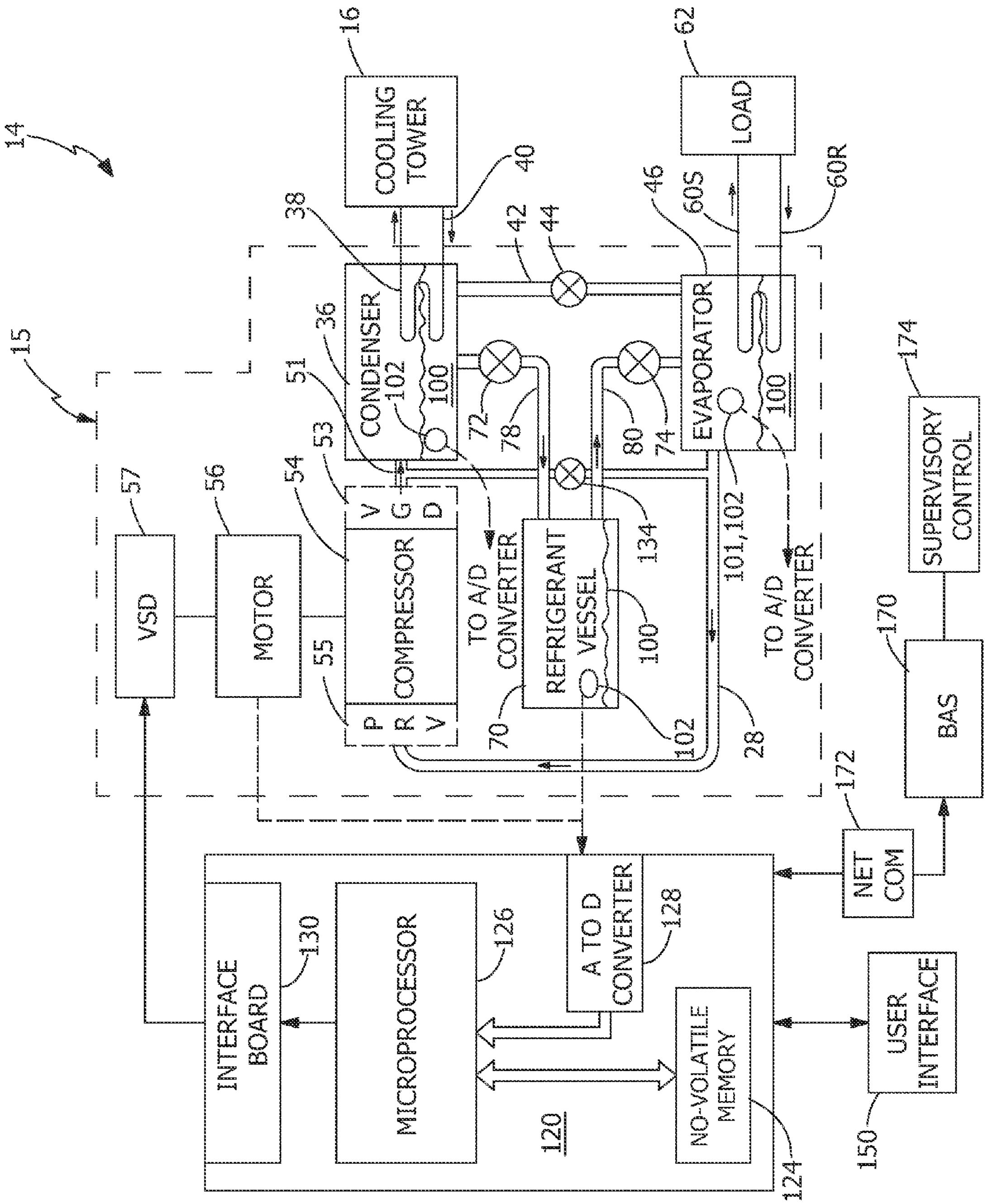

14
15
16
COOLING TOWER
38
40
42
44
46
60S
60R
62
LOAD
CONDENSER
36
102
100
72
78
80
74
EVAPORATOR
51
53
54
V
G
D
COMPRESSOR
55
P
R
V
57
VSD
56
MOTOR
TO A/D CONVERTER
REFRIGERANT VESSEL
134
101,102
TO A/D CONVERTER
70
28
174
SUPERVISORY CONTROL
170
BAS
172
NET COM
A TO D CONVERTER
128
MICROPROCESSOR
126
INTERFACE BOARD
130
NO-VOLATILE MEMORY
124
120
USER INTERFACE
150

FIG. 1

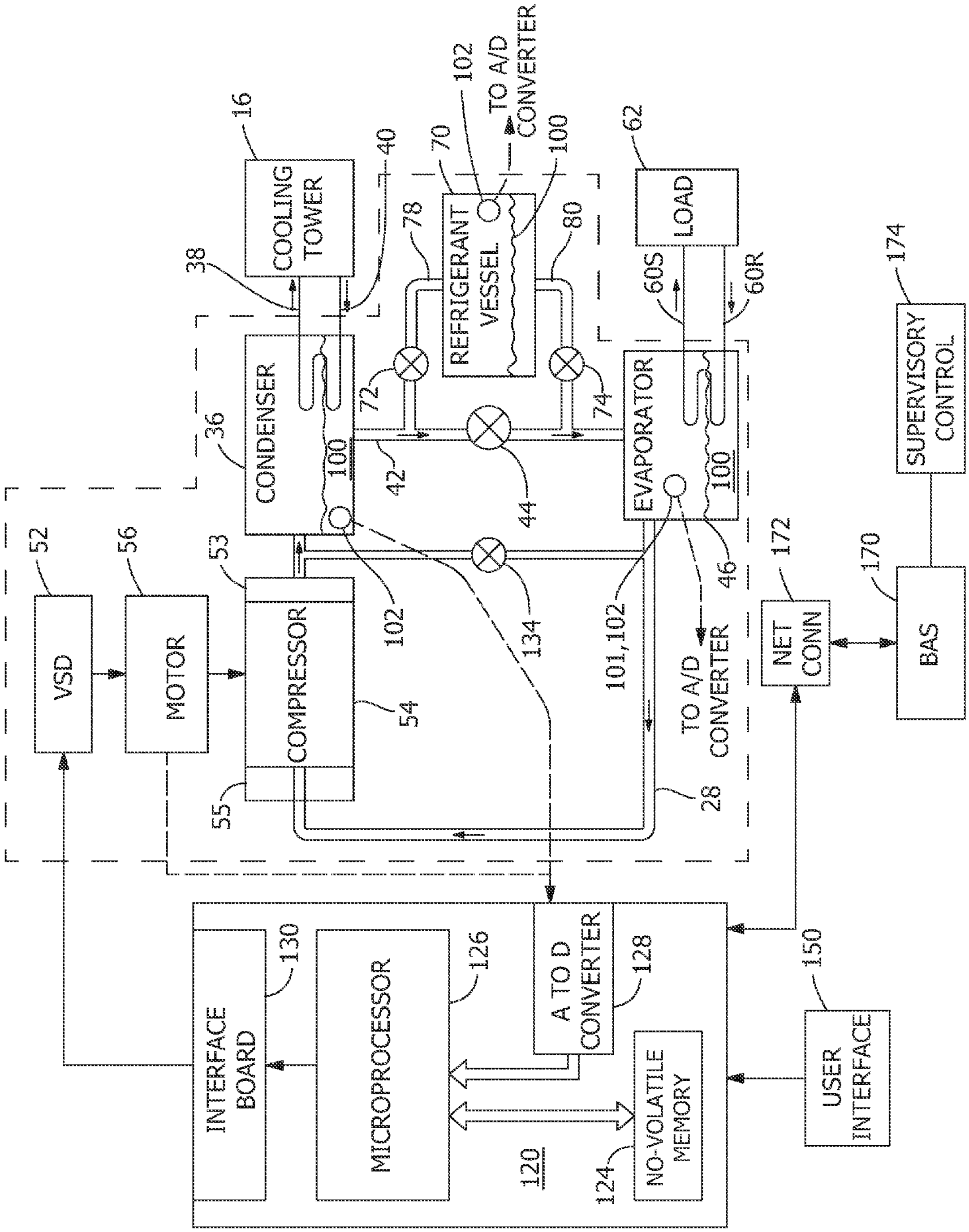

COOLING TOWER
16
38
40
REFRIGERANT VESSEL
70
78
80
102
TO A/D CONVERTER
100
LOAD
62
60S
60R
CONDENSER
36
100
72
74
42
44
EVAPORATOR
100
46
101,102
TO A/D CONVERTER
VSD
52
MOTOR
56
COMPRESSOR
53
54
55
102
134
28
NET CONN
172
BAS
170
SUPERVISORY CONTROL
174
INTERFACE BOARD
130
MICROPROCESSOR
126
A TO D CONVERTER
128
NO-VOLATILE MEMORY
124
120
USER INTERFACE
150

FIG. 2

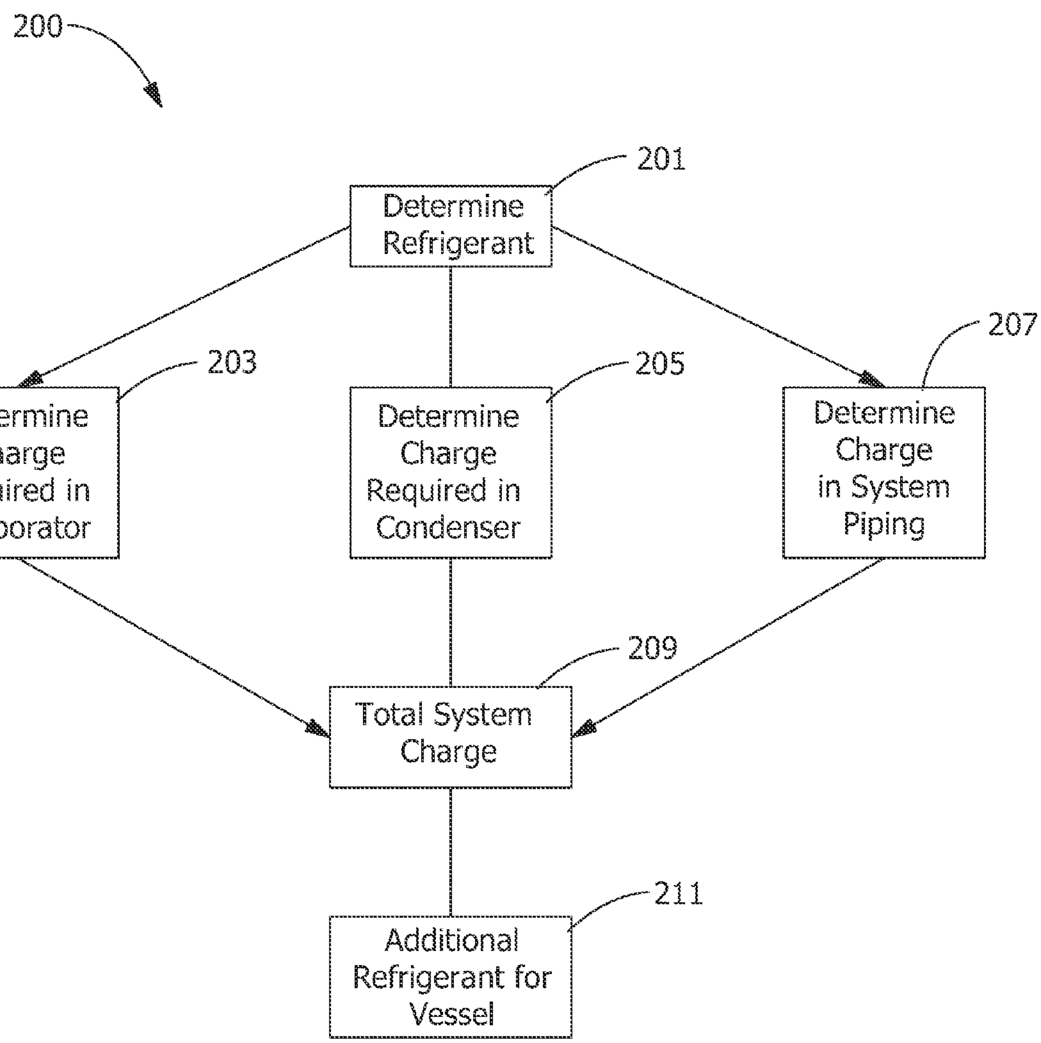
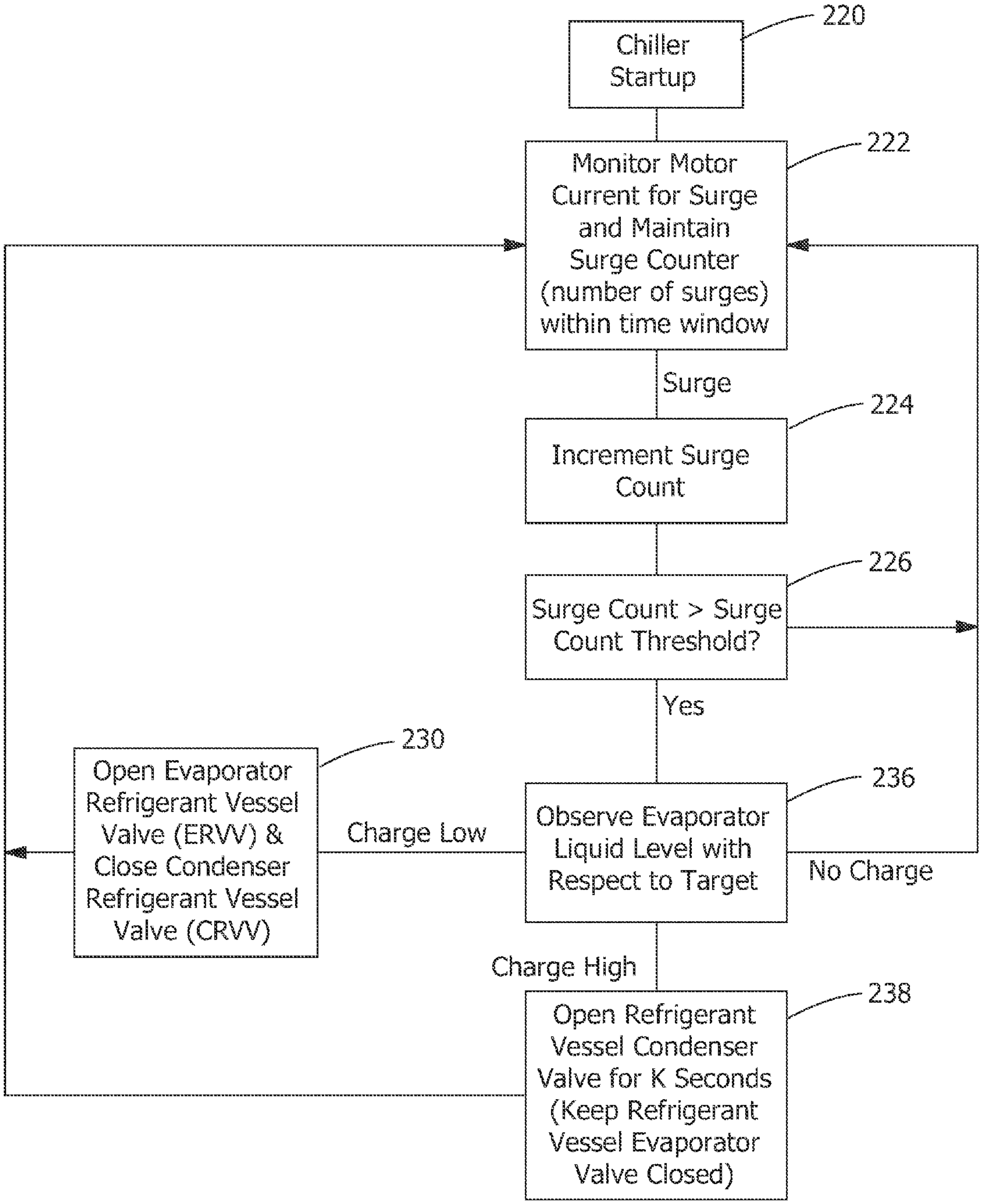

200
201
Determine Refrigerant
203
Determine Charge Required in Evaporator
205
Determine Charge Required in Condenser
207
Determine Charge in System Piping
209
Total System Charge
211
Additional Refrigerant for Vessel

FIG. 3



220
Chiller Startup
222
Monitor Motor Current for Surge and Maintain Surge Counter (number of surges) within time window
Surge
224
Increment Surge Count
226
Surge Count > Surge Count Threshold?
Yes
230
Open Evaporator Refrigerant Vessel Valve (ERVV) & Close Condenser Refrigerant Vessel Valve (CRVV)
Charge Low
236
Observe Evaporator Liquid Level with Respect to Target
No Charge
Charge High
238
Open Refrigerant Vessel Condenser Valve for K Seconds (Keep Refrigerant Vessel Evaporator Valve Closed)

FIG. 4

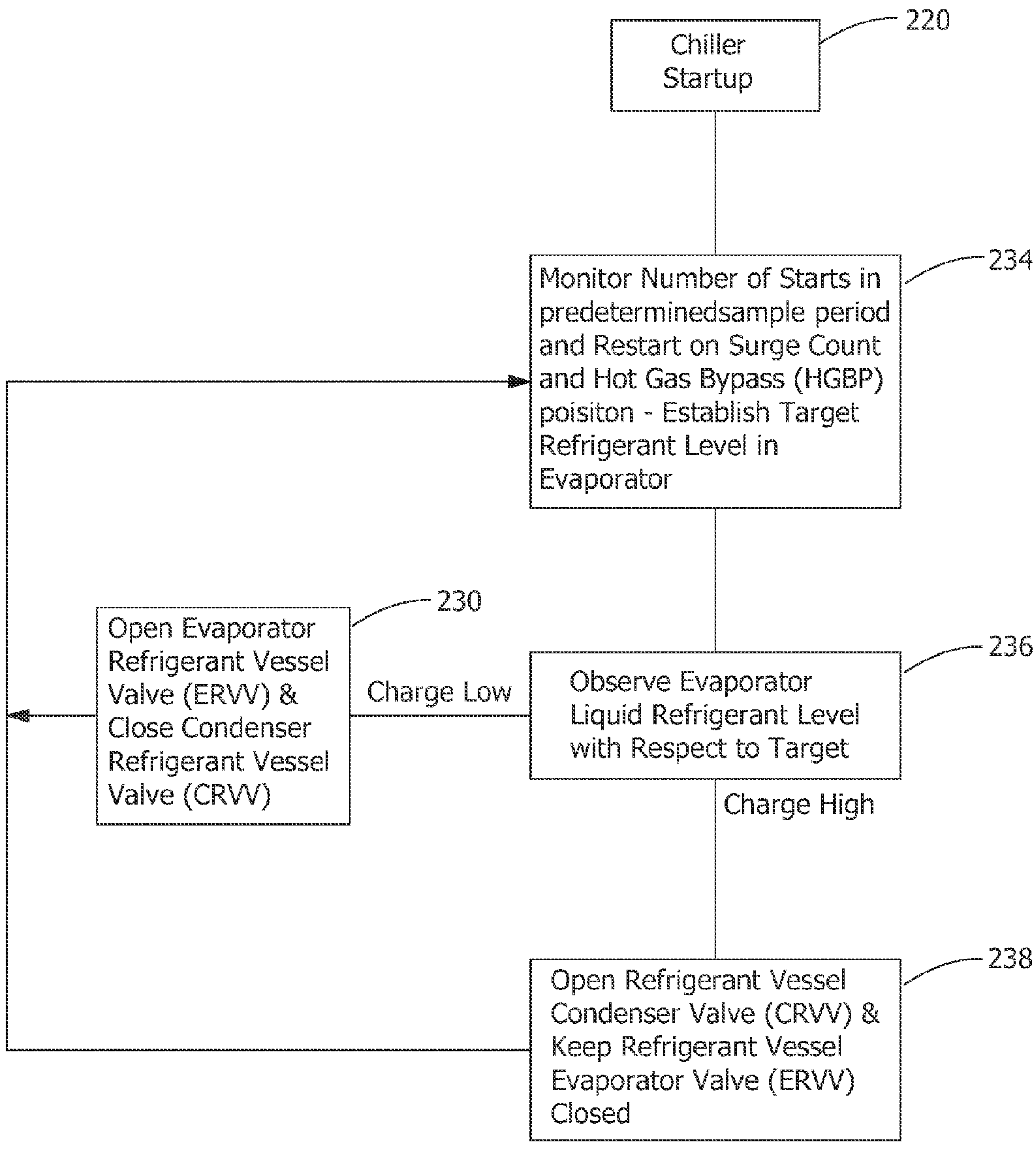

Chiller Startup
220
Monitor Number of Starts in predeterminedsample period and Restart on Surge Count and Hot Gas Bypass (HGBP) poisiton - Establish Target Refrigerant Level in Evaporator
234
230
Open Evaporator Refrigerant Vessel Valve (ERVV) & Close Condenser Refrigerant Vessel Valve (CRVV)
Charge Low
Observe Evaporator Liquid Refrigerant Level with Respect to Target
236
Charge High
Open Refrigerant Vessel Condenser Valve (CRVV) & Keep Refrigerant Vessel Evaporator Valve (ERVV) Closed
238

FIG. 5

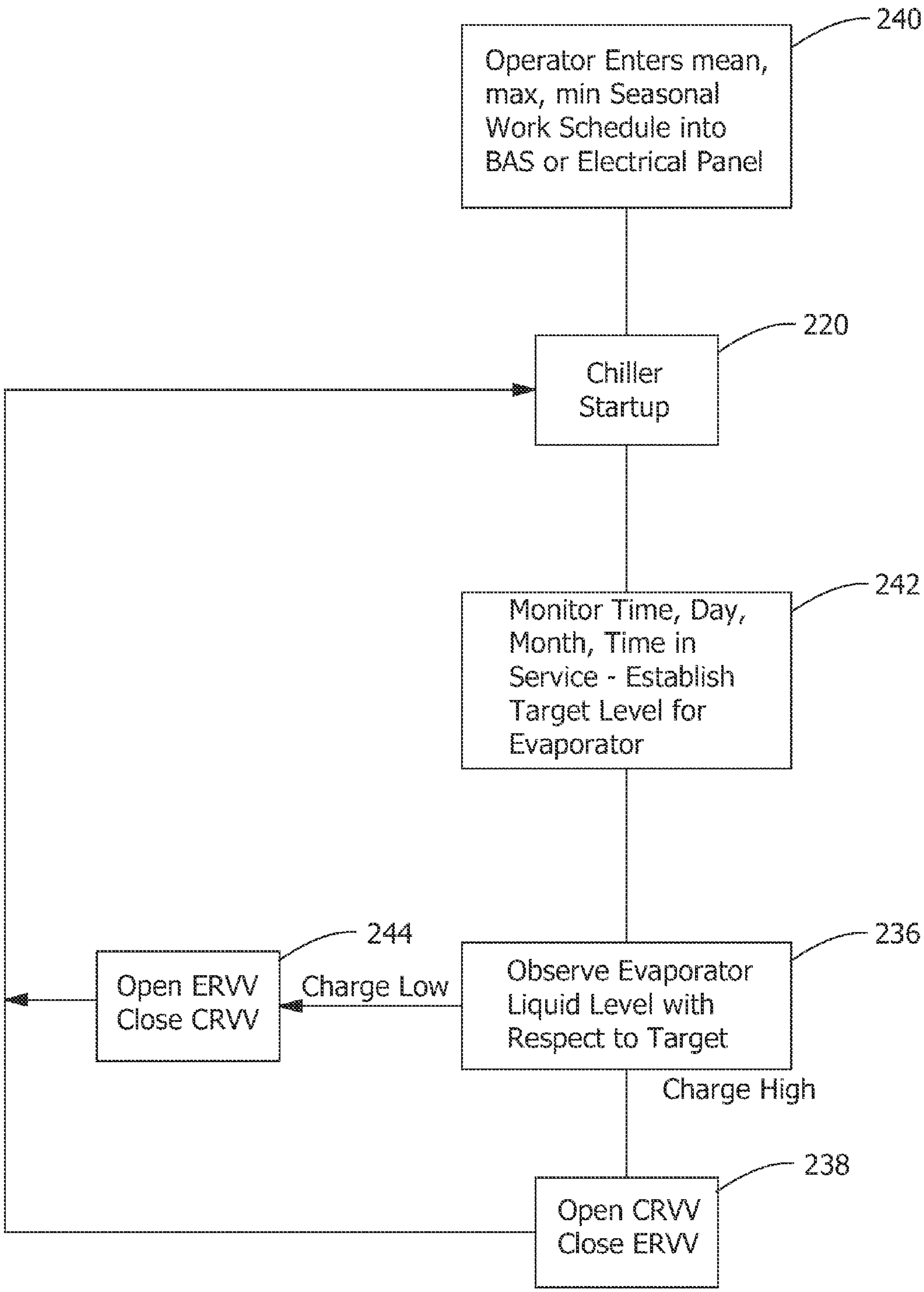

240
Operator Enters mean, max, min Seasonal Work Schedule into BAS or Electrical Panel
220
Chiller Startup
242
Monitor Time, Day, Month, Time in Service - Establish Target Level for Evaporator
244
Open ERVV Close CRVV
Charge Low
236
Observe Evaporator Liquid Level with Respect to Target
Charge High
238
Open CRVV Close ERVV

FIG. 6

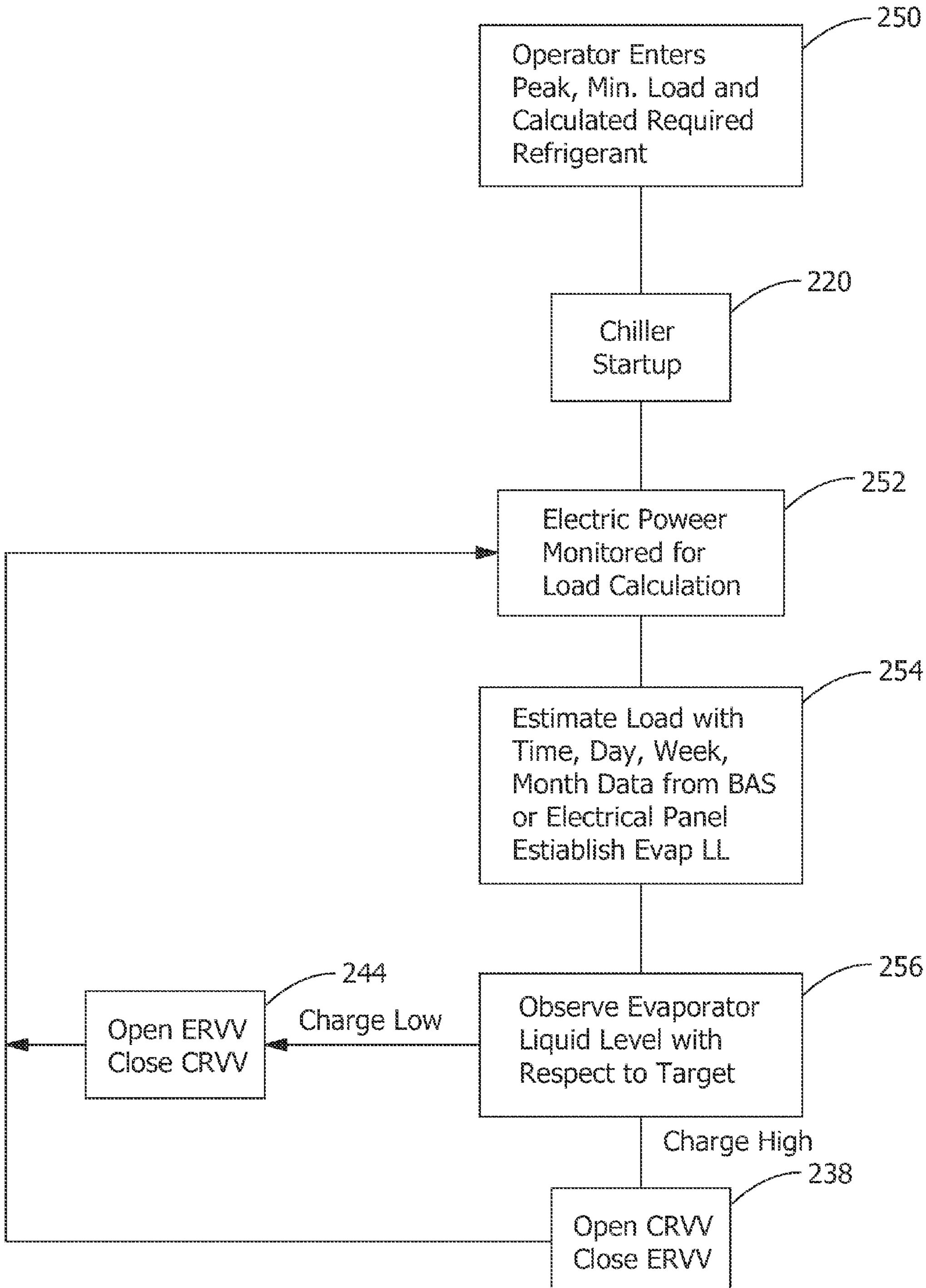

250
Operator Enters Peak, Min. Load and Calculated Required Refrigerant
220
Chiller Startup
252
Electric Poweer Monitored for Load Calculation
254
Estimate Load with Time, Day, Week, Month Data from BAS or Electrical Panel Estiablish Evap LL
256
Observe Evaporator Liquid Level with Respect to Target
Charge Low
244
Open ERVV Close CRVV
Charge High
238
Open CRVV Close ERVV

FIG. 7

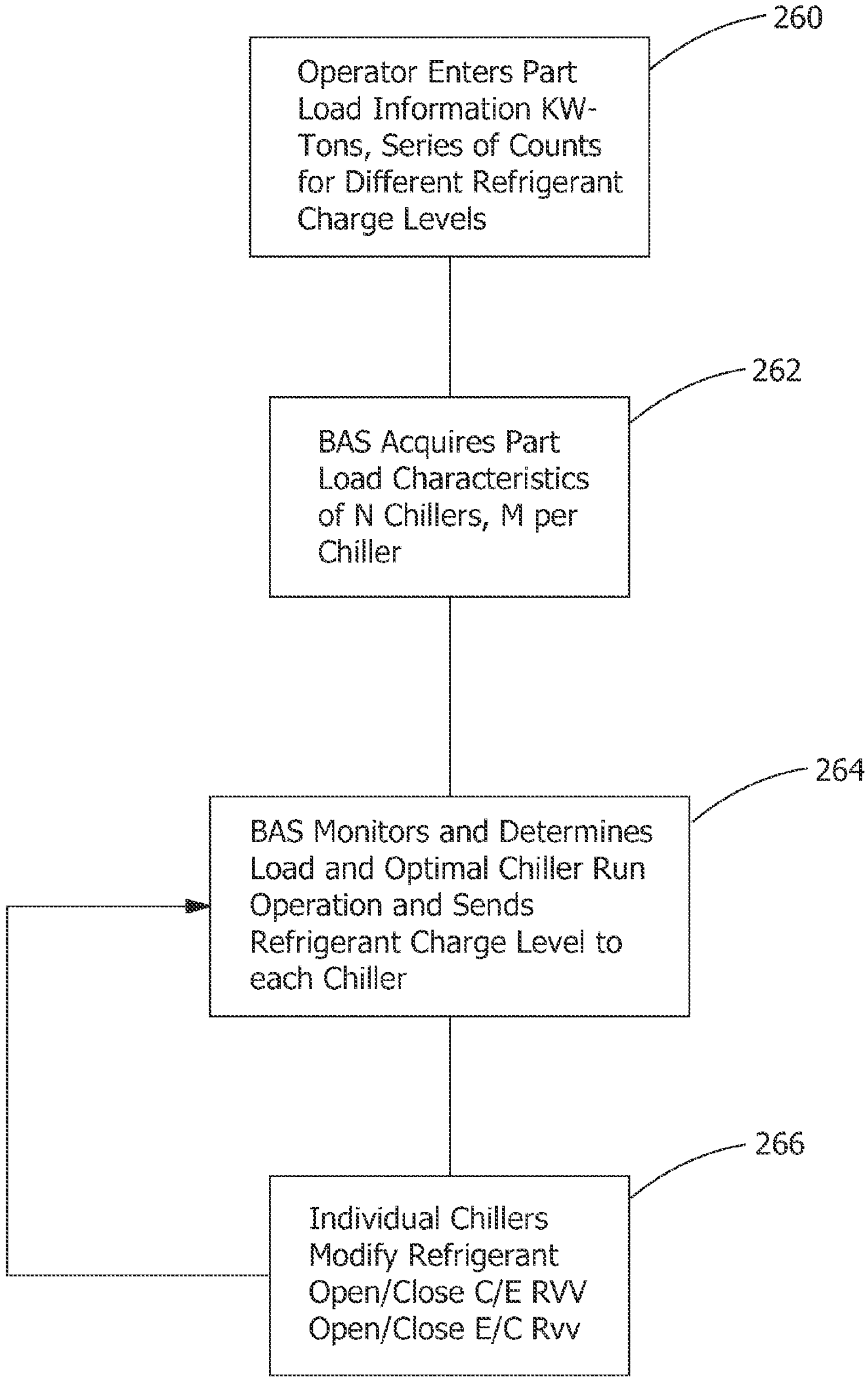

260
Operator Enters Part Load Information KW-Tons, Series of Counts for Different Refrigerant Charge Levels
262
BAS Acquires Part Load Characteristics of N Chillers, M per Chiller
264
BAS Monitors and Determines Load and Optimal Chiller Run Operation and Sends Refrigerant Charge Level to each Chiller
266
Individual Chillers Modify Refrigerant Open/Close C/E RVV Open/Close E/C Rvv

FIG. 8

METHOD AND APPARATUS FOR VARIABLE REFRIGERANT CHILLER OPERATION

CROSS-REFERENCE TO RELATED APPLICATIONS

This application claims the benefit of U.S. Provisional Application No. 61/414,681 entitled "METHOD AND APPARATUS FOR VARIABLE REFRIGERANT CHILLER OPERATION" filed Nov. 17, 2010, which application is hereby incorporated by reference in its entirety.

BACKGROUND

The present disclosure is directed to a method and apparatus for more efficient operation of a refrigeration system. More particularly, the disclosure relates to a method and apparatus for more efficient operation of a variable refrigerant chiller in the refrigeration system, which includes an additional refrigerant vessel to allow for variation of the amount of refrigerant in the refrigeration system.

Conventional chilled liquid systems in vapor compression refrigeration systems used in heating, ventilation and air conditioning systems include a condenser vessel, an evaporator vessel, a compressor, a variable speed drive (VSD), an expansion valve, and optionally a hot gas bypass valve. Operation of a chiller system produces chilled liquid (e.g. water) (T_{ch}) at varying load and cooling tower conditions. To efficiently produce T_{ch}, various compressor elements of the chiller system are employed.

In conventional refrigeration systems, the evaporator effects a transfer of thermal energy between the refrigerant of the system and another liquid to be cooled. As a result of the thermal energy transfer with the liquid, the heat is transferred into the refrigerant converting some of it into vapor, which is then returned to a compressor where the vapor is compressed, to begin another refrigerant cycle. The cooled liquid can be circulated to a plurality of heat exchangers located throughout a building. Warmer air from the building is passed over the heat exchangers where the cooled liquid is warmed, while cooling the air for the building. The liquid warmed by the building air is returned to the evaporator to repeat the process. During operation of the chiller, the liquid level is maintained in the chiller through a control loop utilizing the expansion (throttling) valve to control the height of the liquid level in the condenser vessel. The evaporator also has a mixture of liquid and gas refrigerant. The heat transfer characteristics in the evaporator are affected by the number of tubes "submerged" in the liquid refrigerant versus gas refrigerant.

Chiller operation is desired to control and produce T_{ch} at a setpoint (e.g., 44 degrees F.) under different load conditions in the presence of disturbances such as low load scenarios, medium load scenarios, and high load scenarios. When considering a chiller for purchase there are load considerations that are used to estimate the peak load required to support the operation. This impacts the physical size of the chiller vessels, the number of tubes, size of compressor, and associated piping sizes. In addition, the refrigerant (e.g., R134a) charge is calculated based on the desired heat flux (BTU/hr*ft^2) in the refrigerant system.

Conventional chilled liquid systems provide a fixed amount of refrigerant in the system and thus are only optimized for one operating condition or state. Although conventional chiller systems are designed to run efficiently, over time, the chiller systems are often not running as efficiently as they could be due to fouling or other factors. Thus, there exists a need for chiller systems with variable refrigerant control.

Another situation that is to be avoided in conventional chilled liquid systems is surge. Surge or surging is an unstable condition that may occur during centrifugal compressor operation. Surge is a transient phenomenon having oscillations in pressures and flow, and results in complete flow reversal through the compressor. Surging, if uncontrolled, can cause excessive vibrations in both the rotating and stationary components of the compressor, and may result in permanent compressor damage. One common technique to correct a surge condition may involve the opening of a hot gas bypass valve to return some of the discharge gas of the compressor to the compressor inlet to increase the flow at the compressor inlet.

Therefore, what is needed is a high-efficiency chiller system that allows for efficient chiller operation and that prevents surge during low load conditions. The addition of a variable amount of refrigerant in the system enables another degree of freedom for operation of the chiller by changing the heat transfer characteristics and refrigerant level in the evaporator vessel.

SUMMARY OF THE INVENTION

The present disclosure is directed to a refrigeration system including a compressor, a condenser, an expansion device, an evaporator, and an additional refrigerant vessel connected in a closed refrigerant loop. The present disclosure provides an additional refrigerant vessel that is connected directly to the condenser and directly to the evaporator. Alternately, the additional refrigerant vessel is connected to the existing piping between the condenser and evaporator, usually the expansion valve line. This novel refrigeration system comprises an input valve from the condenser vessel, an additional refrigerant vessel to hold refrigerant, and an output valve to the evaporator vessel. The operation of the valves during a change in refrigerant amount is such that only one valve is open at a time to allow additional refrigerant to enter or be removed from the closed-loop system. If there is no change in refrigerant amount required then both of the valves are closed.

In one embodiment, a refrigeration system is disclosed. The refrigeration system includes a compressor, a condenser, an expansion device, an evaporator, and an additional refrigerant vessel connected in a closed refrigerant loop. The additional refrigerant vessel is connected to the condenser at a high pressure side by a first valve and to the evaporator at a low pressure side by a second valve. A controller controls operation of the first valve and the second valve. Only one of the first valve and the second valve may be open at the same time, to allow additional refrigerant to be added to the closed refrigerant loop when the controller receives a low refrigerant level indication in the evaporator, or to remove refrigerant when the controller receives a high refrigerant level indication of a refrigerant level in the evaporator.

In another embodiment, a method is disclosed for controlling cooling capacity of a chiller system. The chiller system includes having a compressor, a condenser and an evaporator connected in a closed refrigerant loop. The method includes providing a refrigerant vessel for a chiller system; connecting the refrigerant vessel and an outlet line from the refrigerant vessel to the evaporator; connecting an inlet line to the refrigerant vessel to the condenser, the inlet line including a first valve to control flow of refrigerant in the inlet line and the outlet line including a second valve to control flow of refrigerant in the outlet line; monitoring a parameter associated with the compressor for indication of a surge condition in the chiller system; in response to receiving an indication of an impending surge condition, observing a refrigerant liquid

level in the evaporator with respect to surge indication frequency, and adjusting the capacity of the chiller system in response to a change in the refrigerant liquid level in the evaporator.

Another feature of the present disclosure is a method for storing refrigerant in a chiller system, wherein the method includes: opening the outlet valve attached to the evaporator so the pressure in the additional refrigerant vessel is at low evaporator value (e.g., 40 psig), next the outlet valve is closed and the inlet valve next to the condenser is opened for a period of time to move refrigerant at a higher pressure (e.g., 100 psig) to the refrigerant vessel. This method will result in less refrigerant being available to the chiller system and also changes the heat transfer characteristics in the evaporator. During the winter a minimum portion of the refrigerant will be stored in the refrigerant vessel to support part load and in the fall/spring it is expected that the refrigerant stored in the additional refrigerant vessel will increase. During high load conditions or summer months the refrigerant stored in the additional vessel will increase further to provide additional cooling capacity. To move refrigerant into the additional refrigerant vessel, the inlet valve next to the condenser is opened for a period of time to move the refrigerant to the refrigerant tank.

Efficient operation of multiple chillers with VSD drives indicates that operating several chillers at part load is more efficient than operating fewer chillers at full load. Running a chiller at part load limits the RPM of the VSD (generally 30 Hz), which results in the chiller generally running at a lower load condition. When the chiller unit is running at a lower load condition, the chiller unit is more likely or may have a tendency to surge. Surging should be avoided and this system removes additional refrigerant from the chiller system when the additional cooling capacity is not needed, thereby assisting in avoiding surge conditions. Adding refrigerant will decrease compressor head pressure and increase volume flow rate which helps avoid surge at a given RPM speed.

An advantage of the present disclosure is that it can be utilized to reduce the number of chiller geometrical variations required to support different load conditions. Another advantage is that by varying the amount of refrigerant and subsequently the heat transfer characteristics, operation of the chiller can be maintained with potentially lower building loads.

A further advantage is seasonal deployment of the variable refrigerant system (3-4 months frequency). During summer months when a fuller load operation is desired, less refrigerant will be deployed into the chiller system. During the fall/spring a portion of the refrigerant will be stored in the refrigerant vessel and in the winter the refrigerant in the refrigerant vessel will decrease to support part load and avoid surge in low load scenarios.

A further advantage of the present disclosure is that it provides a greater efficiency of chiller operation at part load, thus providing a secondary method to prevent surge or control against surge in the system.

Still a further advantage of the present disclosure is that it provides for a significant annualized energy efficiency improvement over current HVAC systems.

Other features and advantages of the present disclosure will be apparent from the following more detailed description of the preferred embodiment, taken in conjunction with the accompanying drawings which illustrate, by way of example, the principles of the disclosure.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** schematically illustrates an exemplary embodiment of the refrigeration system of the present disclosure.

FIG. **2** schematically illustrates another exemplary embodiment of the refrigeration system of the present disclosure.

FIG. **3** is a block diagram of an exemplary method for calculating the refrigerant in the refrigerant vessel.

FIG. **4** illustrates an exemplary embodiment of a control method for anti-surge operation of a chiller system.

FIG. **5** illustrates an alternate exemplary embodiment of a control method for recycling refrigerant in low load conditions of a chiller system.

FIG. **6** illustrates an alternate exemplary embodiment of a control method for a site specific management of refrigerant charge in a chiller system.

FIG. **7** illustrates an alternate exemplary embodiment of a control method for optimizing the refrigerant level in the evaporator of a chiller system.

FIG. **8** illustrates an alternate exemplary embodiment of a control method for optimizing partial load operation in a multiple chiller system facility.

Wherever possible, the same reference numbers will be used throughout the drawings to refer to the same or like parts.

DETAILED DESCRIPTION

FIG. **1** depicts a Heating, Ventilating, and Air Conditioning (HVAC) system **10** that is typically installed in a building (not shown). The HVAC system **10** includes a cooling tower **16** positioned on the roof of the building. In an exemplary embodiment, cooling tower water is supplied to cooling tower **16** from a condenser **36** by a cooling tower supply line **38**, and cooling tower return water is returned to condenser **36** by cooling tower return line **40**. Condenser **36** is also connected to an evaporator **46**, and to a refrigerant vessel **70**, the operation of which is discussed in detail below. Refrigerant circulates as a gas from a compressor **54**, driven by a motor **56** through refrigerant line **58** to condenser **36** where it undergoes a change of state and is condensed to a liquid. Although compressor **54** is depicted as a single compressor, a closed-loop chiller system **15** may include a plurality of compressors **54** operating in series, in which refrigerant gas flows from a first compressor to a second compressor and so forth prior to circulation to condenser **36**, or in parallel, in which the refrigerant gas is split between multiple compressors **54** prior to being circulated to condenser **36**. Heat is removed from the refrigerant gas in condenser **36**, cooling the refrigerant to a first temperature T_1 by heat exchange with water from the closed loop system connected to heat exchanger **30**. The water in the closed-loop system then circulates to heat exchanger **30**, where heat is removed convectively from the water by air.

Motor **56** used with compressor **54** can be powered by a variable speed drive (VSD) **57** or can be powered directly from an alternating current (AC) or direct current (DC) power source (not shown). VSD **57**, if used, receives AC power having a particular fixed line voltage and fixed line frequency from the AC power source and provides power having a variable voltage and frequency to motor **56**. Motor **56** can include any type of electric motor that can be powered by a VSD or directly from an AC or DC power source. For example, motor **56** can be a switched reluctance motor, an induction motor, an electronically commutated permanent magnet motor or any other suitable motor type. In an alternate exemplary embodiment, other drive mechanisms such as steam or gas turbines or engines and associated components can be used to drive compressor **54**.

In one embodiment, compressor **54** is a centrifugal compressor. In another embodiment compressor **54** is a, screw compressor, reciprocating compressor, rotary compressor, swing link compressor, scroll compressor, turbine compressor, or any other suitable compressor. The refrigerant vapor delivered by compressor **54** to condenser **36** transfers heat to a fluid, for example, water. The refrigerant vapor condenses to a refrigerant liquid in condenser **36** as a result of the heat transfer with the fluid. In the exemplary embodiment, condenser **36** is water cooled and includes a cooling tower supply line and a cooling tower return line connected to cooling tower **16**. The liquid refrigerant from condenser **36** flows through expansion valve **44** to evaporator **46**. In one exemplary embodiment, a liquid chamber **101** may be in placed in fluid communication with evaporator **46** interior on an outer wall of evaporator **46**, and used to facilitate the measuring of liquid level in the evaporator by sensor **102**. Chamber **101** provides a region in the evaporator that is separate from the boiling area so that liquid refrigerant will be present.

As shown in FIGS. **2** and **4**, an additional refrigerant vessel **70** is present to vary the amount of refrigerant **100** in the closed-loop chiller system **15** of vapor compression system **14** to satisfy reduced load requirements during seasonal peaks, and prevent surge at low load conditions, by reducing the amount of refrigerant stored in during off-peak or cold months.

In one embodiment, as shown in FIG. **2**, during the winter months most or all of additional refrigerant **100** in refrigerant vessel **70** will be deployed into closed-loop chiller system **15** to prevent surge at low load conditions. During the fall and spring months refrigerant from closed-loop chiller system **15** will be stored in refrigerant vessel **70** with additional refrigerant **100** (see FIG. **1**). During the summer months excess refrigerant will also be stored in refrigerant vessel **70**. In the present embodiment, the amount of refrigerant may be varied, which subsequently varies the heat transfer characteristics in the closed-loop chiller system, therefore allowing operation of the closed-loop chiller system **15** to be maintained with potentially lower building cooling loads. In FIG. **2**, refrigerant vessel **70** is connected directly to condenser **36** by a first line **78** having an input valve **72** and connected directly to evaporator **46** by a second line **80** having an output valve **74**. The operation of the input valve **72** and output valve **74** is such that only one of the two valves **72**, **74** is open at a time between refrigerant vessel **70** and either condenser **36** and/or evaporator **46**. If there is no change in refrigerant amount required then both input valve **72** and output valve **74** are closed.

In an alternative embodiment, as shown in FIG. **4**, refrigerant vessel **70** is connected to the expansion valve line **42**, which connects to both condenser **36** and evaporator **46**, by a first line **78** and a second line **80**.

Once additional refrigerant **100** is introduced into the closed-loop chiller system **15**, the refrigerant is delivered to evaporator **46**. The evaporator **46** absorbs heat from another fluid, which may or may not be the same type of fluid used for condenser **36**, and undergoes a phase change to a refrigerant vapor. In the exemplary embodiments shown in FIGS. **2** and **4**, evaporator **46** includes a tube bundle having a supply line **60**S and a return line **60**R connected to a cooling load **62**. A process fluid, for example, water, ethylene glycol, calcium chloride brine, sodium chloride brine, or any other suitable liquid, enters evaporator **46** via return line **60**R and exits evaporator **46** via supply line **60**S. Evaporator **46** chills the temperature of the process fluid. The tube bundle in evaporator **46** can include a plurality of tubes and a plurality of tube bundles. The vapor refrigerant exits evaporator **46** and returns to compressor **54** by a suction line **28** to complete the cycle. Refrigerant at temperature T_1 is further cooled in condenser **36** after cooling to temperature T_2 by water from cooling tower **16**, provided by cooling water return line, which may be supplemented by water from cooling tower return water replenishment line **61** (see FIG. **1**).

As shown in FIG. **3**, in the illustrated embodiment, a Modified Refrigerant Charge Calculation Method (MRCCM) may be used to determine an amount of the additional refrigerant **100** to provide in refrigerant vessel **70**. Refrigerant vessel **70** can be sized using a minimum and maximum amount of refrigerant in the chiller system and taking the difference between the two amounts as the amount to be stored in the refrigerant vessel. A method **200** for determining the amount of additional refrigerant **100** for additional refrigerant vessel **70** is described as follows. To begin, at box **201** the type of refrigerant being used is provided. If the refrigerant type is not already known it must be determined at box **201**. Some examples of fluids that may be used as refrigerants in closed chiller system **15** are hydrofluorocarbon (HFC) based refrigerants, for example, R-410A, R-134a, hydrofluoro olefin (HFO) R1234yf, water vapor or any other suitable type of refrigerant. Next, in any order, at box **203** the refrigerant charge required in the evaporator must be determined, at box **205** the refrigerant charge required in the condenser must be determined, and at box **207** the refrigerant charge required in the system piping must be determined. To determine the refrigerant charge in the evaporator (box **203**) equation 1 is used:

$$\text{Charge}_{evap}=LF_{evap}\times\rho_{liq.evap}\times\text{Volume}_{evap} \qquad \text{Equation 1}$$

Where the refrigerant charge in the evaporator (Charge_{evap}) is calculated by multiplying the loading factor of the evaporator (LF_{evap}) by the fluid density of the evaporator ($\rho_{liq.evap}$) by the volume of the evaporator (Volume_{evap}). To determine the refrigerant charge in the condenser (box **205**) equation 2 is used:

$$\text{Charge}_{cond}=\rho_{liq.cond}\times\text{Vol}_{sub}+\rho_{cond.equiv}\times\text{Vol}_{cond} \qquad \text{Equation 2}$$

Where the refrigerant charge in the condenser (Charge_{cond}) is calculated by multiplying the fluid density of liquid in the condenser ($\rho_{liq.cond}$) by volume of the liquid in the subcooler (Vol_{sub}) and adding this product to the product of equivalent fluid density in the condenser ($\rho_{cond.equiv}$) and the volume of fluid the condenser (Vol_{cond}). To determine the refrigerant charge in the system piping (box **207**) equation 3 is used:

$$\text{Charge}_{piping}=F_{piping}\times(\text{Charge}_{evap}+\text{Charge}_{cond}) \qquad \text{Equation 3}$$

Where the refrigerant charge in the system piping (Charge_{piping}) is calculated by multiplying a factor (F_{piping}) representing refrigerant charge in the system piping, which is assumed to be approximately 13% of the total shell charge, by the sum of the charge in the evaporator (Charge_{evap}) and the refrigerant charge in the condenser (Charge_{cond}). Once refrigerant charge in the evaporator is determined at box **203**, the refrigerant charge required in the condenser is determined at box **205**, and the refrigerant charge required in the system piping is determined at box **206**, the total system refrigerant charge (box **209**) can be determined. To determine the total system refrigerant charge (box **209**) equation 4 is used:

$$\text{Charge}_{total}=\text{Charge}_{evap}+\text{Charge}_{cond}+\text{Charge}_{piping} \qquad \text{Equation 4}$$

Where total system charge (Charge_{total}) is calculated by summing the charge in the evaporator (Charge_{evap}) and the charge in the condenser (Charge_{cond}) and the charge in the system piping (Charge_{piping}). The calculated total system charge is used to determine the amount of refrigerant (box **211**) to add to refrigerant vessel **70** to achieve the desired properties for the HVAC system **10**.

Refrigerant vessel **70** can be added to existing HVAC systems **10** with minimal effort by connecting refrigerant vessel **70** to expansion valve line **42** between condenser **36** and evaporator **46**. Refrigerant vessel **70** can also be designed and implemented into new HVAC systems **10** by connecting the refrigerant vessel **70** directly to condenser **36** and evaporator **46** or optionally, connecting refrigerant vessel **70** to expansion valve line **42**. The above MRCCM calculation can be used to determine the amount of additional refrigerant **100** to be charged into refrigerant vessel **70** to provide modified cooling capacity for closed-loop chiller system **15**.

As shown in FIGS. **2** and **4**, chiller equipment controller **120** is in communication with a network connection **172** and Building Automation System (BAS) **170**, which monitors and controls the overall HVAC system **10**. Chiller equipment controller **120** uses a control algorithm(s) to control operation of closed-loop chiller system **15** and to determine when to respond to particular compressor conditions, condenser conditions, and evaporator conditions, in order to maintain closed-loop chiller system **15** stability which, includes preventing stall and surge conditions. Additionally, chiller equipment controller **120** can use the control algorithm(s) to open and close the optional, hot gas bypass valve (HGV) **134**, if present, in response to particular compressor conditions in order to maintain system and compressor stability. In one embodiment, the control algorithm(s) can be computer programs stored in non-volatile memory **124** having a series of instructions executable by microprocessor **126**. While the control algorithm can be embodied in a computer program(s) and executed by microprocessor **126**, it will be understood by those skilled in the art that the control algorithm may be implemented and executed using digital and/or analog hardware. If hardware is used to execute the control algorithm, the corresponding configuration of chiller equipment controller **120** can be changed to incorporate the necessary components and to remove any components that may no longer be required, for example, A/D converter **128**.

Chiller equipment controller **120** may include analog to digital (A/D) and digital to analog (D/A) converters **128**, microprocessor **126**, non-volatile memory or other memory device **124**, and interface board **130** to communicate with various sensors and control devices of closed-loop chiller system **15**. In addition, chiller equipment controller **120** can be connected to or incorporate a user interface **150** that permits an operator to interact with chiller equipment controller **120**. The operator can select and enter commands for chiller equipment controller **120** through user interface **150**. In addition, user interface **150** can display messages and information from chiller equipment controller **120** regarding the operational status of closed-loop chiller system **15** for the operator. The user interface **150** can be located on or near chiller equipment controller **120**, such as being mounted on chiller equipment controller **120**, or alternatively, user interface **150** can be located remotely from chiller equipment controller **120**, such as being located in a separate control room apart from closed-loop chiller system **15**.

Microprocessor **126** may execute or use a single or central control algorithm or control system to control closed-loop chiller system **15** including compressor **54**, condenser **36**, evaporator, refrigerant vessel **70**, and inlet valve **72** and outlet valve **74** from refrigerant vessel **70**. In one embodiment, the control system can be a computer program or software having a series of instructions executable by microprocessor **126**. In another embodiment, the control system may be implemented and executed using digital and/or analog hardware by those skilled in the art. In still another embodiment, chiller equipment controller **120** may incorporate multiple controllers, each performing a discrete function, with a central controller that determines the outputs of chiller equipment controller **120**. If hardware is used to execute the control algorithm, the corresponding configuration of chiller equipment controller **120** can be changed to incorporate the necessary components and to remove any components that may no longer be required.

Chiller equipment controller **120** of closed-loop chiller system **15** can receive many different sensor inputs from the components of closed-loop chiller system **15**. Some examples of sensor inputs to chiller equipment controller **120** are provided below, but it is to be understood that chiller equipment controller **120** can receive any desired or suitable sensor input from a component of closed-loop chiller system **15**. Some inputs to chiller equipment controller **120** relating to refrigerant vessel **70** can be from input valve sensor, output valve sensor, fluid level sensor **102** in refrigerant vessel **70**, pressure sensor in condenser **36**, pressure sensor in evaporator, fluid level sensor **102** in condenser, and fluid level sensor **102** in evaporator **46**.

The central control algorithm executed by microprocessor **126** on chiller equipment controller **120** preferably includes a refrigerant control program or algorithm to control the amount of refrigerant **100** introduced into or removed from refrigerant vessel **70** to run efficiently and prevent surge. The refrigerant control program can automatically determine by monitoring the load conditions and surge conditions the desired amount of additional refrigerant **100**, to add into closed-loop chiller system **15** to allow for higher efficiency operation of the condenser **36** and evaporator **46**.

The refrigerant control program can be configured to maintain selected parameters of closed-loop chiller system **15** within preselected ranges. These parameters include input valve position (open/closed), output valve position (open/closed), fluid level in the refrigerant vessel, fluid level in condenser, and fluid level in evaporator. The refrigerant control program may employ continuous feedback from sensors monitoring various operational parameters described herein to continuously monitor and change the amount of refrigerant **100** in closed-loop chiller system **15**, in response to changes in system cooling loads. That is, as closed-loop chiller system **15** requires either additional or reduced cooling capacity, the amount of refrigerant **100** in the closed-loop chiller system **15** can be varied by opening or closing inlet valve **72** or outlet valve **74** to refrigerant vessel. Existing capacity control methods, e.g., pre-rotation vanes (PRV) **55** at compressor suction line **28**, or a variable geometry diffuser **53** positioned at compressor discharge line **51**, RPM of compressor **54** and evaporator **46** in closed-loop chiller system **15** are correspondingly updated or revised in response to changes in cooling capacity capabilities, as a result of the modified refrigerant **100** amount.

In addition to the refrigerant control program, (BAS) **170** provides additional parameters to allow the HVAC system **10** maintain maximum operating efficiency. BAS **170** includes a supervisory controller **174** and a network connection **172** to chiller equipment controller **120**. Supervisory controller **174** controls chilled water temperature setpoint, turns the chiller system **15** on or off, and determines how the chiller system **15** should run based on time of day, date, season, or any other forward looking profile that is provided to the supervisory controller **174**. Network connection **172** communicates information between BAS **170** and closed-loop chiller system **15**. Network connection **172** relays information to BAS **170** from closed-loop chiller system **15** about operating conditions of closed-loop chiller system **15** such as chilled water set point, current limit (between 0-100 percent usage), and amount of refrigerant in closed-loop chiller system **15**. BAS **170** can control specific components in closed-loop chiller system **15** through the chiller equipment controller **120**. Chiller equipment controller **120** monitors and controls the chiller system components, such as the compressor **54**, condenser **56**, and evaporator **46**, and amount of refrigerant **100** from refrigerant vessel **70** in the closed-loop chiller system **15**. BAS **170** provides non-local, or temperature and pressure independent feedback and data to the chiller equipment controller **120**. BAS **170** provides information acquired from sources that are not available to the local chiller equipment controller **120** such as number of occupants in building **12**, type of day (i.e., sunny, cloudy, windy), weather predictions looking forward, and information on other chillers in the system that may be coming online or turning off. BAS **170** provides information and input to chiller equipment controller **120** to operate efficiently based on non-local parameters such as number of occupants, type of day, etc., thereby making operation of the vapor compression system **14** more efficient annually due to charge management system proposed.

Referring to FIG. **4**, a method of controlling anti-surge in chiller system **15** is described as follows. At box **220**, the chiller startup is completed. Next the method proceeds to box **222** and monitors motor current for an indication of surge. The system maintains a surge counter to count the number of surges occurring within a time window. When at box **222** a surge is indicated, the method proceeds to box **224** and increments a surge count. Next, at box **226**, the method compares the cumulative surge count with a surge count threshold. If the surge count is less than or equal to the surge count threshold, the method returns to box **222**. Otherwise, the method proceeds to box **236**, to observe the liquid refrigerant level in evaporator **46** with respect to a target refrigerant level. If no change is observed in the liquid refrigerant level in evaporator **46** over the predetermined interval, then the system returns to box **222** to monitor motor current for surge indication. At box **236** again, if the evaporator **46** liquid refrigerant level is too high, then the method proceeds to box **238**. At box **238**, the controller **120** opens valve **72** between refrigerant vessel **70** and condenser **36** for a predetermined interval, and maintains valve **74** closed between evaporator **46** and refrigerant vessel **70**. At the end of the predetermined interval valve **74** is closed and the method returns to box **222** to resume monitoring motor current for surge condition. Returning to box **236**, in the event that the refrigerant level in the evaporator is indicating too low, the method proceeds to box **230**, and valve **74** is opened to permit refrigerant flow from refrigerant vessel **70** into evaporator **46**, and valve **72** is closed, causing additional refrigerant from refrigerant vessel **70** to flow back into the refrigerant circuit.

Referring next to FIG. **5**, an alternate embodiment of a control method is shown, for reducing low load recycling of chiller system. The control method of FIG. **5** begins at box **222** with the chiller system startup. After the chiller system startup at box **222** is completed, the control method proceeds at box **234** to monitor the number of start cycles occurring over a predetermined interval, e.g., **24** hours, and the number of chiller system restarts occurring over the same interval on surge count and hot gas bypass valve position, to establish a target refrigerant level for liquid refrigerant in evaporator **46**. Next, at box **236**, the system observes the liquid refrigerant level in evaporator **46** with respect to the target refrigerant level previously established. If the liquid refrigerant level in evaporator **46** exceeds the target refrigerant level by a predetermined amount, the method proceeds to box **238**, wherein valve **72** is opened while valve **74** is kept in the closed position, allowing excess or additional refrigerant in condenser **36** to flow into refrigerant vessel **70**. Observing the liquid refrigerant level in evaporator **46** at box **236** again, if the liquid refrigerant level in evaporator **46** is lower than the target refrigerant level by a predetermined amount, the method proceeds to box **244**, in which valve **74** is opened while valve **72** is kept in the closed position, causing additional refrigerant from refrigerant vessel **70** to flow into evaporator **46** and raise the liquid refrigerant level in evaporator **46**.

Referring next to FIG. **6**, another alternate embodiment of a control method is shown, for control of chiller system **15** using site specific parameters. At box **240**, an operator enters site-specific data, e.g., mean chiller system capacity, maximum chiller system capacity, minimum chiller system capacity; or seasonal or weekly schedule, into BAS **170** or other electrical control panel **120**. Next, at box **220**, chiller system startup is initiated, and the system proceeds at box **242** to monitor data points such as the time, day, month and time in service, and based on the monitored data points the method establishes a target refrigerant level for liquid refrigerant in evaporator **46**. Next, at box **236**, the system observes the liquid refrigerant level in evaporator **46** with respect to the target refrigerant level previously established. If the liquid refrigerant level in evaporator **46** exceeds the target refrigerant level by a configurable amount, the method proceeds to box **238**, wherein valve **72** is opened while valve **74** is kept in the closed position, allowing excess or additional refrigerant to flow from condenser **36** into refrigerant vessel **70**. Observing the liquid refrigerant level in evaporator **46** at box **236** again, if the liquid refrigerant level in evaporator **46** is lower than the target refrigerant level by a predetermined amount, the method proceeds to box **244**, in which valve **74** is opened while valve **72** is kept in the closed position, causing additional refrigerant to flow from refrigerant vessel **70** into evaporator **46** and raise the liquid refrigerant level in evaporator **46**.

Referring next to FIG. **7**, another alternate embodiment of a control method is shown, for optimizing the liquid refrigerant level of evaporator **46** based on an estimated load. At box **250**, an operator enters peak load and minimum load parameters and calculates the required amount of refrigerant required to operate chiller system **15** (see, e.g., FIG. **3**). The control method then proceeds to box **220**, to start chiller system **15**. Next, the control method proceeds to box **252** and monitors electrical control panel **120** to determine motor load associated with motor **56**, and calculates the chiller system load **62**. After calculating the chiller system load **62**, the method proceeds at box **254** to estimate the chiller system capacity with the time, day, week and month data from BAS **170** or electrical control panel **120** to establish a target refrigerant level for liquid refrigerant in evaporator **46**. Next, at box **236**, the system observes the liquid refrigerant level in evaporator **46** with respect to the target refrigerant level previously established. If the liquid refrigerant level in evaporator **46** exceeds the target refrigerant level by a configurable amount, the method proceeds to box **238**, wherein valve **72** is opened while valve **74** is kept in the closed position, allowing excess or additional refrigerant to flow from condenser **36** into refrigerant vessel **70**, thereby lowering the liquid refrigerant level in evaporator **46**. If, however, the liquid refrigerant level in evaporator **46** is lower than the target liquid refrigerant level by a predetermined amount, the method proceeds to box **244**, in which valve **74** is opened while valve **72** is kept closed, causing additional refrigerant to flow from refrigerant vessel **70** into evaporator **46** and raise the liquid refrigerant level in evaporator **46**. Referring next to FIG. **8**, another alternate embodiment of a control method is shown, for optimizing a multiple-unit chiller plant for partial load operation. Beginning at box **260**, an operator enters partial load information in units of kilowatts or tons of cooling capacity, and a series of curves for efficient refrigerant change levels. Next the method proceeds to box **262**, and BAS **170** acquires partial load characteristics for N chillers, M curves per chiller. The method then proceeds to box **264**, wherein BAS **170** monitors chiller system load **62** and determines optional chiller operation, including an evaporator refrigerant level for each of the chiller units that make up the chiller plant. The BAS **170** transmits the determined evaporator refrigerant level to each chiller control panel **120**. Next, the method proceeds at box **266** to modify evaporator refrigerant levels for each individual chiller by opening and closing valves **72**, **74**, according to one or more of the control methods set forth above with respect to FIGS. **4-7**.

Refrigerant vessel **70** may also provide a temporary refrigerant storage capacity when performing maintenance or repairs on chiller system **15**. If necessary to drain chiller system **15** of refrigerant, e.g., to make repairs to condenser **36**, refrigerant **100** may be transferred from condenser **36** via valve **72** into refrigerant vessel **70**, where the refrigerant **100** may maintained by closing both valves **72** and **74** during the maintenance or repair operations. When ready to resume operation, refrigerant **100** may be replaced into chiller system via valve **74** to evaporator **46**.

While only certain features and embodiments of the disclosure have been shown and described, many modifications and changes may occur to those skilled in the art (for example, variations in sizes, dimensions, structures, shapes and proportions of the various elements, values of parameters (for example, temperatures, pressures, etc.), mounting arrangements, use of materials, colors, orientations, etc.) without materially departing from the novel teachings and advantages of the subject matter recited in the claims. The order or sequence of any process or method steps may be varied or re-sequenced according to alternative embodiments. Furthermore, in an effort to provide a concise description of the exemplary embodiments, all features of an actual implementation may not have been described (i.e., those unrelated to the presently contemplated best mode of carrying out the disclosure, or those unrelated to enabling the claimed disclosure). It should be appreciated that in the development of any such actual implementation, as in any engineering or design project, numerous implementation specific decisions may be made. Such a development effort might be complex and time consuming, but would nevertheless be a routine undertaking of design, fabrication, and manufacture for those of ordinary skill having the benefit of this disclosure, without undue experimentation.

As noted above, embodiments within the scope of the present application include program products comprising machine-readable media for carrying or having machine-executable instructions or data structures stored thereon. Such machine-readable media can be any available media that can be accessed by a general purpose or special purpose computer or other machine with a processor. By way of example, such machine-readable media can comprise RAM, ROM, EPROM, EEPROM, CD-ROM or other optical disk storage, magnetic disk storage or other magnetic storage devices, or any other medium which can be used to carry or store desired program code in the form of machine-executable instructions or data structures and which can be accessed by a general purpose or special purpose computer or other machine with a processor. When information is transferred or provided over a network or another communications connection (either hardwired, wireless, or a combination of hardwired or wireless) to a machine, the machine properly views the connection as a machine-readable medium. Thus, any such connection is properly termed a machine-readable medium. Combinations of the above are also included within the scope of machine-readable media. Machine-executable instructions comprise, for example, instructions and data which cause a general purpose computer, special purpose computer, or special purpose processing machines to perform a certain function or group of functions.

It should be noted that although the figures herein may show a specific order of method steps, it is understood that the order of these steps may differ from what is depicted. Also two or more steps may be performed concurrently or with partial concurrence. Such variation will depend on the software and hardware systems chosen and on designer choice. It is understood that all such variations are within the scope of the application. Likewise, software implementations could be accomplished with standard programming techniques with rule based logic and other logic to accomplish the various connection steps, processing steps, comparison steps and decision steps.

The invention claimed is:

1. A refrigeration system comprising:

a compressor, a condenser, an expansion device, an evaporator, and an additional refrigerant vessel connected in a closed refrigerant loop;

the additional refrigerant vessel connected to the condenser at a high pressure side by a first valve and to the evaporator at a low pressure side by a second valve;

a controller to control operation of the first valve and the second valve, wherein only one of the first valve and the second valve is open at a time to allow additional refrigerant to be added to the closed refrigerant loop in response to the controller receiving a low refrigerant level indication of a refrigerant level in the evaporator, or to remove refrigerant from the closed refrigerant loop in response to the controller receiving a high refrigerant level indication of a refrigerant level in the evaporator, a chamber in fluid communication with the evaporator; and a fluid level sensor disposed within the chamber to provide a direct measurement of the refrigerant level to the controller;

the controller configured to:

count the number of surges occurring within a predetermined interval;

increment a surge count when a surge is indicated;

compare the surge count with a surge count threshold; and

in response to the surge count exceeding the surge count threshold:

observe a liquid refrigerant level in the evaporator with respect to a target refrigerant level; and

in response to observing no change in the liquid refrigerant level over the predetermined interval, return to the step of monitoring a parameter associated with the compressor and monitor a motor current for surge indication.

2. The refrigeration system of claim **1**, wherein only one of the first valve and the second valve may be open between the additional refrigerant vessel and the condenser or the evaporator.

3. The refrigeration system of claim **1**, wherein the additional refrigerant vessel is connected to the expansion valve line and the expansion valve line is connected to the condenser by a first line and to the evaporator by a second line.

4. The refrigeration system of claim **1**, wherein the controller determines an amount of additional refrigerant to be used in the additional refrigerant vessel based on a total refrigerant charge comprising the sum of a condenser refrigerant charge, an evaporator refrigerant charge, and system piping refrigerant charge.

5. The refrigeration system of claim **4**, wherein the controller computes the evaporator refrigerant charge by the equation:

$$Charge_{evap}=LF_{evap}\times\rho_{liq.evap}\times Volume_{evap}$$

Where:

($Charge_{evap}$)=the refrigerant charge in the evaporator

(LF_{evap})=the loading factor of the evaporator

($\rho_{liq.evap}$)=by the fluid density of the evaporator

($Volume_{evap}$)=by the volume of the evaporator.

6. The refrigeration system of claim **4**, wherein the controller computes the condenser refrigerant charge by the equation:

$$Charge_{cond}=\rho_{liq.cond}\times Vol_{sub}+\rho_{cond.equiv}\times Vol_{cond}$$

where:

($Charge_{cond}$)=the refrigerant charge in the condenser

($\rho_{liq.cond}$)=the fluid density of liquid in the condenser

(Vol_{sub})=the volume of the liquid in the subcooler

($\rho_{cond.equiv}$)=equivalent fluid density in the condenser and

(Vol_{cond})=the volume of fluid the condenser.

7. The refrigeration system of claim **4**, wherein the controller computes the system piping refrigerant charge by the equation:

$$Charge_{piping}=F_{piping}\times(Charge_{evap}+Charge_{cond})$$

where:

($Charge_{piping}$)=the refrigerant charge in the system piping

(F_{piping})=factor (%) of refrigerant charge in the system piping

($Charge_{evap}$)=the charge in the evaporator and

($Charge_{cond}$)=the refrigerant charge in the condenser.

8. The refrigeration system of claim **4**, wherein the controller computes a total system refrigerant charge by the equation:

$$Charge_{total}=Charge_{evap}+Charge_{cond}+Charge_{piping}$$

where:

$Charge_{total}$=the total system refrigerant

($Charge_{evap}$)=the refrigerant charge in the evaporator

($Charge_{cond}$)=the refrigerant charge in the condenser

($Charge_{piping}$)=the refrigerant charge in the system piping.

9. The refrigeration system of claim **7**, wherein the factor (%) of refrigerant charge in the system piping is approximately 13% of the sum of the evaporator refrigerant charge and the condenser refrigerant charge.

10. The refrigeration system of claim **7**, wherein the total system refrigerant charge is used to determine an amount of refrigerant to add to the refrigerant vessel.

11. A refrigeration system comprising:

a compressor, a condenser, an expansion device, an evaporator, and an additional refrigerant vessel connected in a closed refrigerant loop;

the additional refrigerant vessel connected at an inlet to an expansion valve inlet line from the condenser, and at an outlet to an expansion valve outlet line from the evaporator; and

a controller configured to control operation of a first valve and a second valve, wherein only one of the first valve and the second valve may open at any time to allow refrigerant from the additional refrigerant vessel to be added to the closed refrigerant loop in response to the controller receiving a low refrigerant level indication of a refrigerant level in the evaporator, or to remove refrigerant from the closed refrigerant loop in response to the controller receiving a high refrigerant level indication of a refrigerant level in the evaporator, a chamber in fluid communication with the evaporator; and a fluid level sensor disposed within the chamber to provide a direct measurement of the refrigerant level to the controller;

the controller configured to:

count the number of surges occurring within a predetermined interval;

increment a surge count when a surge is indicated;

compare the surge count with a surge count threshold; and

in response to the surge count exceeding the surge count threshold:

observe a liquid refrigerant level in the evaporator with respect to a target refrigerant level; and

in response to observing no change in the liquid refrigerant level over the predetermined interval, return to the step of monitoring a parameter associated with the compressor and monitor a motor current for surge indication.

12. The refrigeration system of claim **11**, wherein the controller maintains a plurality of selected parameters of the closed refrigerant loop within preselected ranges.

13. The refrigeration system of claim **12**, wherein the plurality of selected parameters comprises: an input valve position, an output valve position, a fluid level in the refrigerant vessel, a fluid level in condenser, or a fluid level in evaporator.

14. The refrigeration system of claim **13**, wherein the controller employs continuous feedback from a plurality of sensors monitoring the respective selected parameters to continuously monitor and change the amount of refrigerant in the refrigeration system in response to changes in system cooling loads.

15. The refrigeration system of claim **14**, wherein the refrigerant level in the closed refrigerant loop can be varied by opening or closing the first valve or the second valve, and a capacity control device is correspondingly updated or revised in response to changes in cooling capacity capabilities resulting from the modified refrigerant level.

16. A method for controlling cooling capacity of a chiller system having a compressor, a condenser and an evaporator connected in a closed refrigerant loop, the method comprising:

providing a refrigerant vessel for a chiller system;

connecting the refrigerant vessel and an outlet line from the refrigerant vessel to the evaporator;

connecting an inlet line to the refrigerant vessel to the condenser, the inlet line including a first valve to control flow of refrigerant in the inlet line and the outlet line including a second valve to control flow of refrigerant in the outlet line;

monitoring a parameter associated with the compressor for indication of a surge condition in the chiller system;

in response to receiving an indication of an impending surge condition, directly observing a refrigerant liquid level in the evaporator with respect to surge indication frequency, and

adjusting the capacity of the chiller system in response to a change in the refrigerant liquid level in the evaporator, a chamber in fluid communication with the evaporator; and a fluid level sensor disposed within the chamber to provide a direct measurement of the refrigerant level to the controller;

counting the number of surges occurring within a predetermined interval;

incrementing a surge count when a surge is indicated;

comparing the surge count with a surge count threshold; and

in response to the surge count exceeding the surge count threshold:

observing a liquid refrigerant level in the evaporator with respect to a target refrigerant level; and

in response to observing no change in the liquid refrigerant level over the predetermined interval, returning to the step of monitoring a parameter associated with the compressor and monitoring a motor current for surge indication.

17. The method of claim **16**, wherein the parameter is a motor current flowing in a compressor motor.

18. The method of claim **16**, wherein the step of adjusting the capacity comprises:

in response to an increase in the refrigerant liquid level in the evaporator with respect to instances of surge indications over a predetermined period, opening the first valve to allow refrigerant to flow from the condenser into the refrigerant vessel to decrease the cooling capacity of the chiller system.

19. The method of claim **18**, wherein the step of adjusting the capacity further comprises:

in response to a decrease in the refrigerant liquid level in the evaporator with respect to instances of surge indications over a predetermined period, opening the second valve to allow refrigerant to flow from the refrigerant vessel into the evaporator to increase the cooling capacity of the chiller system.

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